Bi-Directional Reflectance Distribution (BRDF) Measurements and Modeling

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LONG-TERM GOALS

My work involves experimentally investigating the interrelationships and variability of optical properties in the ocean and atmosphere. My goal is to define the variability of the optical properties, particularly those dealing with light scattering, and to improve the prediction capabilities of image and radiative transfer models used in the ocean. My near term ocean optics objectives have been: 1) to improve the measurement capability of measuring the in-water and above-water spectral radiance distribution including polarization, 2) to investigate the variability of the Point Spread Function (PSF) as it relates to the imaging properties of the ocean, and 3) to improve the characterization of the Bi-directional Reflectance Distribution Function (BRDF) of benthic surfaces in the ocean, and 4) to understand the capabilities and limitations of using radiative transfer to model the BRDF of particulate surfaces.

OBJECTIVES

Our overall objective in this work is to provide the experimental and theoretical foundation to obtain both a predictive model of the BRDF of benthic surfaces in the ocean and determine the information that may be obtained about the benthic surface from measurement of the BRDF.

APPROACH

To give our modeling efforts a firm experimental foundation we have been making measurements of various prepared surfaces in the laboratory. These measurements have been made with both the in-situ BRDF instrument we built earlier (Voss et al., 2000) and a laboratory Goniometer. The BRDF instrument allows us to quickly measure the BRDF for many illumination angles, and with varied azimuthal angles. The laboratory goniometer allows us to measure smaller phase angles (to look closer to the hotspot), to measure the BRDF at finer angular resolution, and to measure the polarization properties of the BRDF from sediments and other samples. In this effort we are making measurements of spherical particles, surfaces with interstitial liquids of varied indices of refraction and absorption properties, surfaces of natural sediments, and investigating the polarization properties of the BRDF.

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Our theoretical approach is to compare these experimental results with various existing modeling ideas and with ray tracing models to determine the feasibility and accuracy of a predictive approach to the BRDF.

WORK COMPLETED THIS YEAR

We have finished a re-measurement of the Labsphere calibration plaque, both dry and submerged in water, used in calibrations of dry and underwater BRDF (Voss and Zhang, 2006).

We have completed extensive measurements of dry, wet, and submerged surfaces of various sediment particles from opaque grains to beach sand containing clear quartz particles (Zhang and Voss, 2006).

We have finished the measurents on the effect of absorbing interstial liquids on the overall reflectance (albedo) and BRDF of a surface. The results have been written up and will be submitted soon.

We have finished most of the polarized BRDF measurements of various particluate surfaces with constituent particles ranging from natural benthic sediments and mono-dispersed spheres.

We are in the process of summarizing the BRDF work completed in past years and the results will be published as a book chapter (Kokhnovsky, 2007).

Modeling:
We have applied the intimate mixture formula (Hapke, 1993) to predict the albedos of mixtures of ooid sand and glass frits.

We have upgraded the Monte Carlo based ray tracing simulation for calculating the BRDF to deal with more realistic media with random particle properties and compared results with experimental results for submerged versus dry media

RESULTS

For background, our measurements in the field (Zhang et al, 2003) showed that for natural submerged sediments the dominant feature was enhanced backscattering. Our measurements on prepared surfaces (Zhang and Voss, 2005) showed that many single scattering features of the particulates making up a surface, are still contained in the bulk BRDF measurement, but the single scattering features appear muted in the bulk measurement.

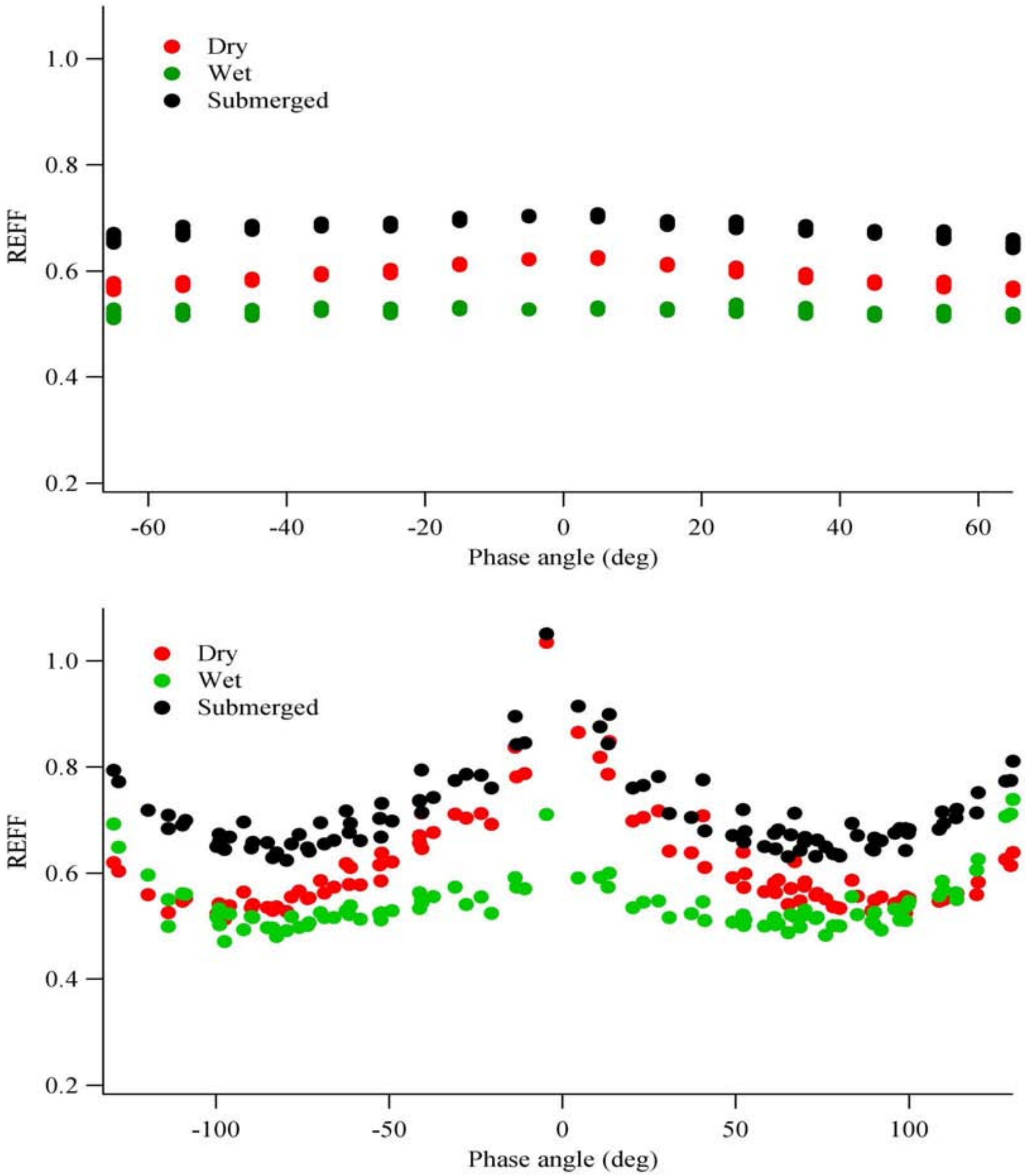

Figure 1) REFF of natural ooid when dry, wetted with water and submerged in water. Top figure is illumination at 0 degrees, lower figure shows illumination at 65 degrees. These figures show that the hotspot in the sample (0 deg phase angle, direct backscattering) decreases when wetted, and there is a slight increase in the forward scattering (evident at 65 degree illumination) when the sample is wetted. It is also important to note that the sample REFF actually is highest when the sample is submerged, and lowest when the sample is wetted.

In our comparisons of dry and wetted surfaces we have found several consistent features. Figure 1 shows the REFF (BRDF normalized to the BRDF of a 100% lambertian reflector) at two different illumination angles, 0 and 65 degrees. This is a natural sample, obtained from sediments at Lee Stocking Island in the Bahamas during the ONR CoBOP program. This sample consists of 0.25-0.50 mm smooth rounded grains.

The effect of wetting is to decrease the REFF overall, decrease the effect of the hotspot (direct backscattering), and cause a slight increase in the forward scattering. What we have found however, is that the decrease in the REFF or albedo is due to several effects. The first seems to follow the predictions of Twomey et al (1986) where the wetted surface has increased forward scattering (as evidenced in the sample above illuminated at 65 degrees). However another effect is related to the concentraton of clear, quartz like particles in the sediment. Wetting these sediments causes an additional darkening as it allows more light to enter the surface of the particles (reduces the effective particle surface roughness) and transmit deeper into the sediment where it has a larger chance of being absorbed.

There is also an interesting effect when the sample is wetted versus submerged. For this submerged sample, the REFF is actually higher than for the same sample when wetted or dry. This is similar to the effect that a plastic diffuser has when submerged (the emersion effect, Tyler and Smith, 1970). We have found that this varies from sample to sample. We performed an experiment, where the concentration of transparent particles in a sample was varied. We found that the albedo of submerged samples tends to decrease as the concentration of transparent particles increases, while the albedo of dry samples tends to increase. At low concentrations of transparent particles, the albedo of the submerged sample is higher than the dry sample. At approximately 80% transparent particles, the dry and submerged samples have the same albedo, while above 80% transparent particles the submerged albedo is less than the dry albedo. The difference between the wet sample and the submerged sample, is that the air-water interface on the submerged sample is far from the sample, thus has little afffect on the measured albedo. In the case of the wetted sample, the air-water interface must trap additional light, hence making the sample look darker.

Using our Monte Carlo based ray tracing simulations of media with random particle properties we were able to gain insight into this mechanism. We calculated the BRDF for a variety of proportions of clear to lambertian particles in both the submerged and dry states. In Fig. 2 we show an example of some of these calculations with different proportions of clear (refractive) or lambertian spheres of a single size in a regular close packed array. The regularity of the positions and sizes of the sphere leads to sharper features compared to natural media but the effects of submerging the media in water are clearly demonstrated.

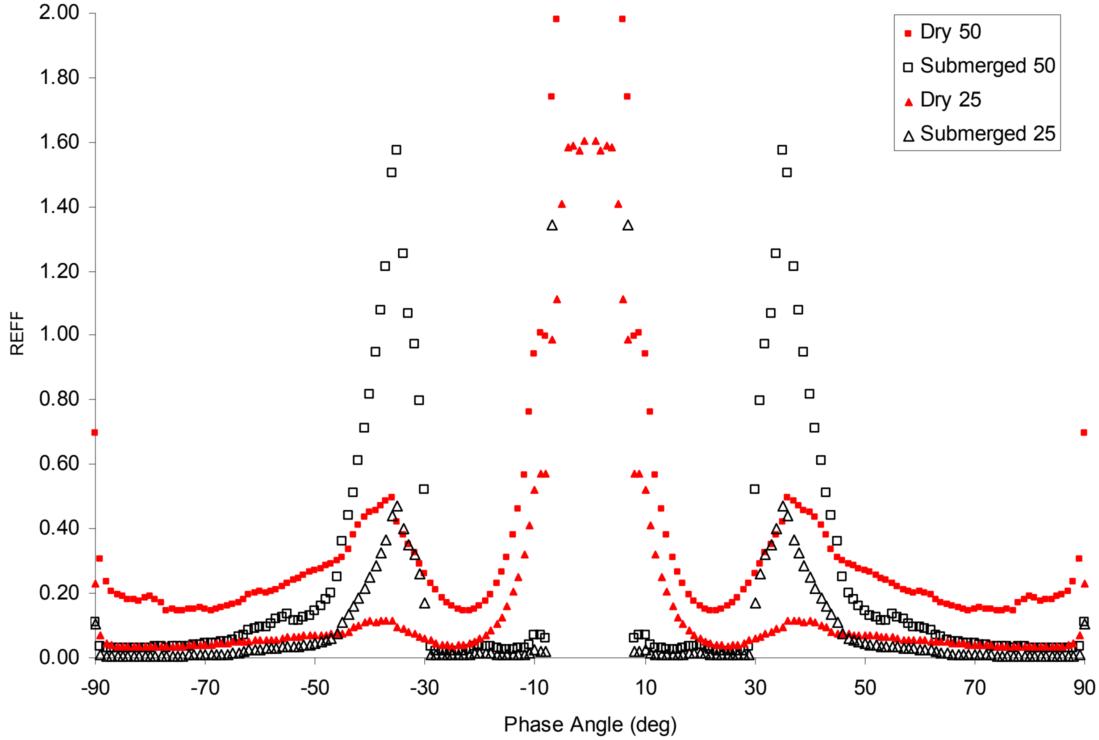

Figure 2) REFF for mixtures of lambertian and clear spheres in a regular close packed array when dry or submerged in water calculated via Monte Carlo ray tracing simulation. Illumination is at 0 degrees. Data is for 50% and 25% proportions of clear spheres. At these proportions the submerged media show enhanced hot spots and lower overall REFF when compared to dry media.

In Fig. 3 we show some of the results from our experiments looking at the effect of an interstitial absorbing liquid. This effort was started so that we might be able to quantfiy how an absorbing liquid, such as CDOM, might modify the reflectance of a marine sediment. As can be seen, the major affect of the absorbing liquid is to decrease the overall reflectance of the sample, as might be expected. In terms of CDOM, the interesting issue is that the liquid must be very highly absorbing (>1 cm^{-1}) before there is a significant affect. This is not surprising as we have shown that only the very near surface in the sediment is important in determining the scattering properties.

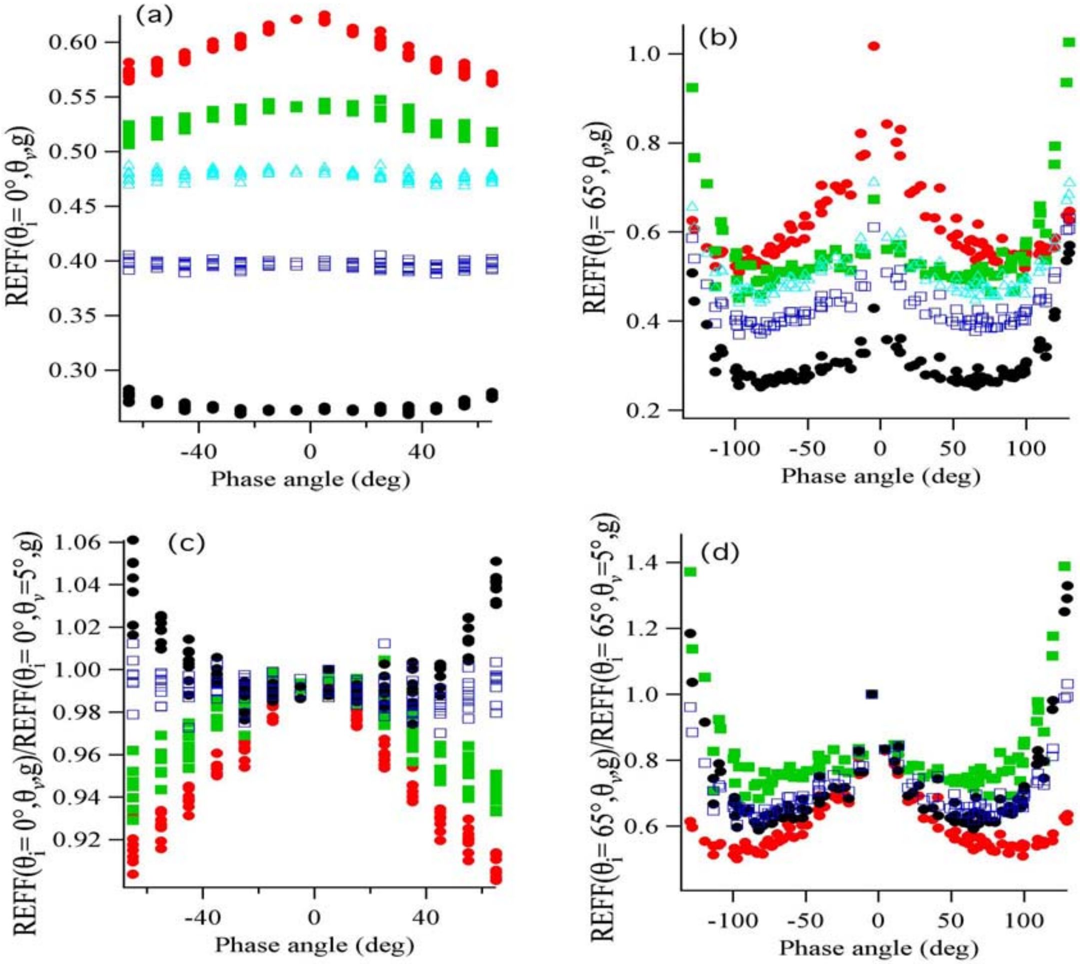

Figure3) Dry, water and 3 absorbing solutions wetted REFF of Sediment A. (a) Normal incidence (b) 65°-incidence (c) Normal incidence, normalized and (d) 65°-incidence, normalized. Solid circles-dry; solid squares-water wetted; open triangles-6.5 cm^{-1} ; open squares-10.49 cm^{-1} ; open circles-40.80 cm^{-1} . For clarity, those of 2.54 cm^{-1} are not shown in (c) and (d). It can be seen that the effect of wetting with absorbing liquids is both to decrease the overall reflectance of the sample and to make the sample more lambertian. However at the highest absorption coefficients the samples tend to increase their forward scattering (reflectance at higher phase angles) relative to the backscattering.

IMPACT/APPLICATIONS

Predicting the BRDF of in-situ benthic surfaces is important for understanding both the natural solar illuminated light field near the bottom and the possible distribution of light from active systems. Since the BRDF is the root source of all remotely sensed data, understanding this factor is important for analyzing all types of remote sensing data.

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PUBLICATIONS

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